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CKD USE AS A SLUDGE STABILIZING, DEWATERING AND DISINFECTION AGENT IN IRAQ

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ABSTRACT

Hundreds of thousands of tons of cement kiln dust (CKD) as well as other emissions are generated annually from existing cement plants in Iraq. Most plants dispose of CKD near or around the plants site as uncovered mounds and piles with significant economic and environmental impacts. The amount of generated CKD is found to be variable among different cement plants. It can be estimated that the generated CKD on the average is about (8-33) % of the production output depending on the conditions of each plant.

An experimental laboratory work on one of the beneficial uses of CKD was carried out in this study. CKD was mixed with sewage sludge as dry alkaline stabilizing agent. Sludge treated with CKD was found to meet the class A requirements (fecal coliform density less than 1000 MPN/g solid) as set by USEPA. In this study, the fecal coliform density of thickened sludge treated with 20 % CKD was reduced from 2.43×10^8 MPN/g to 410 MPN/g, while; for dewatered sludge treated with 30 % CKD, it was reduced from 8.75×10^7 MPN/g to 220 MPN/g. CKD was successfully applied to destroy pathogens, reduce vector attraction and bring the sludge to a manageable form.

Keywords: Cement Kiln Dust (CKD), Iraqi Cement Plants, Sanitary Sludge Stabilizing.

1- Introduction

Although sanitation in Iraq cities is not yet as required level, but a huge amounts of sludge expected to be rejected and disposed to the environment in the near future. Conjunction with lack of available sludge treatment technology, several problems could be created due to high water content and pathogens of disposed sludge. Many studies and research works where performed by Iraqi engineers and researchers to solve this problem. Apart of them concentrates to use the disposed CKD from cement manufacturing plants.

The physical characteristics of fresh CKD are a fine, dry alkaline dust that readily absorbs water. CKD particle sizes generally vary by kiln process type and range from 0-5 micrometers (µm) (approximately clay size) to greater than 50 µm (silt size). The chemical composition of the primary bulk constituents in CKD (those found in quantities greater than 0.05 percent by weight) are silicates, calcium oxide, carbonates, potassium oxide, sulfates, chlorides, various metal oxides, and sodium oxide. Also that variability in raw feed, fuels, process types and product specifications may influence CKD chemical characteristics.

There are many existing plants of cement production working in Iraq which are generating thousands tons yearly of by-product (CKD) which by current practices of managing and disposing have caused, and may continue to cause contamination of air, nearby surface water and ground water, also pose a danger to human health and environment and it may do so in the future.

One of the most important options for making use of CKD is mixing it with sludge resulting from sewage treatment plants as stabilizing/solidifying agent. Where absorptive capacity and alkaline properties of CKD can reduce the moisture content and provide an alkaline environment for waste materials (sludge) (Naik et al., 2003; USEPA, 1993). This approach to wastes utilization allows not only saving natural resources, but also avoiding the negative environmental impact of waste disposal and land filling (Paulauskas et al., 2006). A laboratory study was conducted to determine if CKD could be used as dry-alkaline stabilization agent to stabilize the sewage sludge in accordance with EPA criteria for PSRP. This study was applied on a sewage sludge produced at Al-Rustamiyah sewage treatment plant. Usually, effluent and disposal sludge from this plant are used for land application. At Al-Rustamiyah sewage treatment plant, the sludge passes to the drying bed without significant stabilization of organic matter. Due to the function absence of plant's digesters which are out of service from many years ago, the sludge on the drying beds becomes septic again which creates serious troubles (Al-Najjar, 2001), as well as having high densities of fecal coliform bacteria as shown later.

Dry alkaline stabilization of sewage sludge by using CKD is a treatment intended to destroy pathogens, reduce vector attraction and odors, and bring the sludge to a manageable form for land application. Fecal coliforms bacteria tests are used as an indicator or measure of the effectiveness of stabilization process in reducing microbial densities in sludge (Christine et al., 2007).

2- Quantity and Quality of CKD in Iraq

The survey of the sixteen cement plants which are grouped into three regional companies of cement was prepared as data collection worksheet and distributed to all plants. Approximately, more than 85 percent of the cement plants have been responsive to the survey. Some of the responses may not provide accurate or complete data for many reasons. To minimize the non-response and the lack of data, information submitted by plants in response to the survey was supplemented and evaluated against data obtained from other sources. These other sources include sampling and measurement activities, data collection from documents and reports; site visits observations and utilizing the published international experience in this field.

The production capacity of Iraq cement industry which is distributed over three regional state companies is shown in table (1) which consisted of (79 %) produced by dry process kilns and the remaining (21%) produced by wet process kilns.

Table (1): Production Capacity of Cement General State Companies (USAID, 2007; State Owned Enterprises Guide, 2005).

Company	Wet Process Capacity (1000 Ton/Year)		Dry Process Capacity (1000 Ton/Year)		Overall Capacity (1000 Ton/Year)	
	Available	Designed	Available	Designed	Available	Designed
Northern	402	875	1321	3950	1723 (10.5%)	4825 (29%)

Iraqi	0	0	2226	5290	2226 (13%)	5290 (32%)
Southern	1434	2600	1040	3940	2474 (15%)	6540 (39%)
Total	1836 (11%)	3475 (21%)	4587 (27.5%)	13180 (79%)	6423 (38.5%)	16655 (100%)

An understanding of the issues surrounding CKD requires knowledge of both the raw materials and the fuels (process input) used in cement kiln systems, because these inputs in conjunction with the manufacturing process determine the characteristics and quantities of CKD generated. Fuel inputs can significantly influence CKD chemical characteristics especially sulfur level. Table (2) shows the characteristics of heavy fuel oil used as a source of heat required in cement manufacturing process at all cement plants. The designed and actual heat consumption is shown in Table (3) for all cement plants of the three cement companies. While table (4) is showing the designed and interdependent conversion factor (the quantity of raw materials required to produce unit of product) for all cement plants.

Table (2): Characteristics of Heavy Fuel Oil Used for the Burning in Cement Rotary Kilns (from Documents and Reports of Cement Plants (DAROCP)).

Chemical properties		Physical Properties	
Components	**Average wt %**	**Property**	**Value**
Ash	0.02-0.04	Sp.Gr	0.94
Hydrogen	11	Calorific value	9670 kcal/kg oil
Carbon	85	Pour point	10 ^{0}C
Sulphur	3.5	Flash point	65 ^{0}C
moisture	< 1		

Table (3): Fuel Consumption for Iraqi Cement Plants, from (DAROCP).

Cement Plants of	Fuel Consumption (k cal / kg Clinker)		
	Designed	Actual	% of deviation
Northern Co.			
Old Badoosh	1700	2000	17.6
Badoosh/2	900	1100	22
Badoosh/3	950	1250	31.5
Sinjar	1000	1200	20
Old Hammam Al Aleel	1750	2000	14.3
New Hammam Al Aleel	1750	2000	14.3
Iraqi Co.			
Al Qaim	840	1100	31
Kubaisa	820	1100	34
White Falluja	1500	1750	17
Kirkuk	840	1100	31
Southern Co.			
Old Kufa	1550	1800	16.1
New Kufa	1550	1755	13.2
Al-Muthana	950	1500	57.8
Al- Janoob/Samawa	1750	2100	20
Kerbala	950	1500	57.8
Sadda	1750	2000	14.3
Total Average	1284	1578	22.8

Table (4): Conversion Factor for Cement Plants, from (DAROCP).

Cement Plant	Conversion Factor		
	Designed	Interdependent Now	% Of Deviation
Northern Co.			
Old Badoosh	1.62	1.76	8.6
Badoosh/2	1.70	1.85	8.8
Badoosh/3	1.76	1.90	8.0
Sinjar	1.72	1.92	11.6
Old Hammam Al Aleel	1.62	1.76	8.6
New Hammam Al Aleel	1.62	1.76	8.6
Sector Average	**1.67**	**1.82**	**9.0**
Iraqi Co.			
Al Qaim	1.76	2.0	13.6
Kubaisa	1.74	1.95	12
White Falluja	1.75	1.92	9.7
Kirkuk	1.76	2.0	13.6
Sector Average	1.75	1.97	12.2
Southern Co.			
Old Kufa	1.72	1.90	10.5
New Kufa	1.72	1.90	10.5
Al-Muthana	1.77	2.30	29.9
Al- Janoob/Samawa	1.80	2.20	22.2
Kerbala	1.80	2.40	33
Sadda	1.79	1.92	7.3
Sector Average	1.76	2.10	19.0
National Average	**1.73**	**1.96**	**13.4**

In Iraq, specific data on CKD waste were sparse. A sampling and analysis program was conducted to determine the specific characteristics of CKD at different sources and to integrate the results with available data from plants documents and reports. In addition, dust emission measurements were carried out at different plants to determine the concentration of dust emitted from stacks.

Method and instruments used to quantify and qualify the CKD were as follows:

- Dust emission from stacks was measured according to ASTM D 2928-71; standard method for sampling stacks for particulate matter. The tests were carried out by using **FLS miljo mini-samp^{TM}** equipment.

- Particle size distribution specified by using soil hydrometer, 152 H-62 ASTM, 0 – 60 g/l.
- Chemical analysis of cement and CKD were done according to ASTM C-114. Also, this method determines the oxides of silica, aluminum, iron, calcium, magnesium, sulfur.
- Alkali materials (sodium and potassium oxides) measured according to ASTM C-114 using flame photometer model JENWAY – PFP7.
- pH measured by using pH-meter according to ASTM D-4972.
- Water holding capacity measured according to ASTM D-2216.

The mean of chemical analysis of CKD which generated is shown in table (5), and the particle size distribution and other physical properties are shown at table (6) for different cement plants of the three cement companies.

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Table (5): Chemical analysis of CKD.

	Northern cement plant's samples			Iraqi cement plant's samples			Southern cement plant's samples		
omponents (wt%)	ample No. 1 adoosh)	ample No.2 Sinjar)	ample No.3 amm-am l Aleel)	ample No. 1 l Qaim)	ample No. 2 Kirkuk)	ample No. 3 Falluja)	ample No. 1 (Kufa)	ample No. 2 Muthana)	ample No. 3 erbala)
CaO	45.8	48.0	49.2	45.5	47.2	49.7	41.9	48.2	44.9
Al_2O_3	6.1	4.8	3.9	5.0	4.8	5.0	4.6	3.8	3.1
SiO_2	17.2	15.6	15.2	14.2	15.3	17.1	13.1	17.4	14.5
Fe_2O_3	2.5	2.1	3.1	3.1	1.9	0.3	2.5	3.8	2.7
MgO	3.1	2.1	1.6	2.3	2.7	1.4	3.4	2.7	1.9
SO_3	7.8	5.9	8.1	6.1	6.9	6.6	6.2	5.5	7.6
Na_2O	1.1	0.6	0.8	1.3	1.9	0.9	2.1	1.3	1.4
K_2O	1.3	0.7	0.9	1.8	2.1	1.1	2.7	1.4	1.6
s on Ignition	17.5	20.1	16.5	18.4	18.3	19.4	22.2	17.1	21.9

Table (6): CKD Particle Size Distribution and Other Physical Properties.

Wet process						
Particle size (μ)	Ave Sample No. 1 (Old Badoosh)		Ave Sample No. 2 (Hammam Al-Aleel)		Ave Sample No. 3 (Kufa)	
	percent	Cumulative percent	percent	Cumulative percent	percent	Cumulative percent
< 10	48	48	50	50	54	54
10-20	35	83	31	81	33	87
20-30	8	91	9	90	8	95
30-40	5	96	7	97	4	99
> 40	4	100	3	100	1	100
Dry process						
Particle size (μ)	Ave Sample No. 1 (Sinjar)		Ave Sample No. 2 (Kubaisa)		Ave Sample No. 3 (Al-Muthana)	
	percent	Cumulative percent	percent	Cumulative percent	percent	Cumulative percent
< 10	70	70	75	75	71	71
10-20	19	89	15	90	13	84
20-30	7	96	4	94	9	93
30-40	2	98	3	97	4	97
> 40	2	100	3	100	3	100
Bulk Density (gm / ℓ)			800 – 850			
Water holding capacity (at atmospheric pressure)			(80 – 85) %			
pH			10.5 - 13			

3- Experimental Work

3-1. Materials: Thickened and dewatered sludge were used in this study. Thickened sludge (raw sludge) from outlet of thickening unit and dewatered sludge from the drying bed from Al-Rustamiyah sewage treatment plant/ Baghdad were taken as samples. Before CKD addition, the two sludge types were tested for pH, total solid (TS), volatile solid (VS) and fecal coli-form densities (FC). Results are shown in table (7). The properties of CKD which is used as alkaline agent are shown in table (8).

Table (7): Characteristics of Thickened and Dewatered Sludge before CKD Addition.

Parameter	Thickened sludge	Dewatered sludge
pH	6.7	6.8
TS %	7.0 %	16.0 %
VS %	74.0 %	63.0 %
FC (MPN/g solid)	2.43×10^8	8.75×10^7

Table (8): Characteristics Of CKD Added To Sludge.

Chemical composition (wt %)				Physical characteristics	
CaO	50.7	SO_3	7.3	pH	12.8
Al_2O_3	5.2	Na_2O	1.1	Bulk density	840 gm/l
SiO_2	17.1	K_2O	1.6	Particle size	< 10 µ 84 %

Fe_2O_3	**0.4**	**L.O.I.**	**19.8**		**10-40µ 13 %** **> 40 µ 3 %**
MgO	**1.8**				

3-2. Experimental Procedure: Before CKD addition, characteristics of thickened and dewatered sludge were examined as shown previously in table (7). Then, six samples of thickened sludge and six samples of dewatered sludge were mixed with different doses of CKD in order to obtain stabilized sludge. The dosages ranged between (5-40) gm of CKD to 100 gm sludge (5-40 % weight/weight). Sludge and CKD were mixed manually with a glass rod in the glass bowls to obtain good homogeneity. A screening test was then carried out to determine which mix proportions produced the required pH (at least pH $\geq$ 12 for the first 2 hours and pH $\geq$ 11.5 for the next 22 hours). The resulting mixtures of sludge and CKD were conveyed after 6 hours into the perforated bottom cylinders of experimental lab apparatus which was constructed to accelerate the drying process of treated sludge by supplied air. The mixtures of thickened and dewatered sludge with CKD which satisfied the initial pH requirement were monitored at different time intervals. Further tests involving TS, VS, moisture content, and FC densities were also measured at different time intervals (0, 2, 12, 24, 48, 72, 96, 120, 144 and 168 hours).

3-3. Apparatus of Drying: A small scale drying apparatus, as shown in figure (1), was constructed to accelerate drying of stabilized sludge samples. This apparatus consists of multi cylinder tubes (with 10 cm diameter and 20 cm in height) welded at the ceiling of steel box structure (10 cm high, 30 cm wide and 50 cm long). The ceiling plate of box which represents the bottom of the cylinder tubes was perforated at each one. An air blower (BBC, Type QUXY 90 L 2 AAT, 0.75 kw, 2860 rpm) was used to supply air to the system (connected to the box) during the experiments. The air supplied was released from the box through perforated plate to the cylinder tubes which contain a mixture of stabilized sludge to accelerate drying. If the resulting mixtures were in the cake form, the air drying process was initiated. However, if the resulting mixtures were in liquid form, it was left in the tubes to drain well through the bottom perforated plate to an intermediate solid level to produce a cake material.

Figure (1): Lab apparatus used for treated sludge drying

3-4. Determination of pH: The pH of the sludge and the alkaline stabilized sludge were determined at specified time intervals. A portable pH meter (Corning Model Check- Mate 90 with a glass electrode) was used for the analysis. Table (9) shows the pH values of treated sludge with different CKD addition at different time intervals for both thickened and dewatered sludge.

Table (9): pH Values of Treated Sludge.

pH para-meter	Thickened Sludge Treated With						Dewatered Sludge Treated With					
	5 % CKD	10 % CKD	15 % CKD	20 % CKD	30 % CKD	40 % CKD	5 % CKD	10 % CKD	20 % CKD	25 % CKD	30 % CKD	40 % CKD
After 2 hr	11.2	11.8	12.2	12.4	12.5	12.5	10.8	11.5	11.9	12.2	12.5	12.5
After 12 hr			11.7	11.9	12.1					11.8	12.2	
After 24 hr			11.3	11.6	11.8					11.4	11.7	

After 72hr				**11.3**							**11.5**	
After 120hr				**11.1**							**11.2**	
After 168hr				**11.0**							**11.1**	

3-5. Determination of Total and Volatile Solids: The total solids and the volatile solids concentrations of the sludge were determined by placing a known volume of each sludge type in an evaporating porcelain dish and following the procedures established in the Standard Methods. Total solids are those remaining after the water is driven off by heating the sludge sample at (103-105) ^{o}C.

Total solids percent are calculated by the following equation **(APHA, 1995)**:

$$\%TS = \frac{A - B}{C - B} \times 100 \qquad \text{...} \ (a)$$

Where:

A = weight of dish plus dried sample, g.

B = weight of dish, g.

C = weight of dish plus wet sample, g.

Moisture content is a measure of water in sludge. Percent of moisture content is equal to (1-% TS). After the total solids were determined, the dried residue was placed in a 550 ^{o}C furnace for sixty minutes to drive off the volatile solids. Volatile solid is a measure of the organic matter content of the sludge **(Vesilind, 1979)**. Volatile solid content is usually quoted as a percentage of the total solide residue as follow **(APHA, 1995)**:

$$\%VS = \frac{W_{VS}}{W_{TS}} \times 100 \qquad \text{……………………………..} \ (b)$$

Where:

W_{VS} = weight of volatile solid and

W_{TS} = weight of dry solid.

Table (10) shows the moisture content, total and volatile solids percent for both thickened and dewatered sludge treated with 20 % and 30 % CKD, respectively at different time intervals.

3-6. Analytical Procedure for Fecal Coliform Determination: Bacterial analyses performed in this study included fecal coliforms (FC). Fecal coliform tests were performed according to standard method (SM 9221E) by using the multiple tube procedure **(USEPA, 1999)**. Concentrations of fecal coliform bacteria were reported as the MPN per 100 ml or MPN per gram dry solid. The MPN value is determined from the number of positive tests in a set of five replicate made at three different dilutions. A series of test tubes as shown in figure (2) containing (LTB) broth were inoculated with sewage sludge and incubated for 24 ± 2 hours at 35 ± 0.5 ^{o}C.

Table (10): Total Solid, Volatile Solid and Moisture Content Of Treated Thickened and Dewatered Sludge.

Time intervals	Thickened sludge treated with 20 % CKD			Dewatered sludge treated with 30 % CKD		
	TS %	VS %	MC %	TS %	VS %	MC %
After 24 hr	37.8	25.3	62.2	48.4	19.1	51.6
After 48 hr	49.5	24.2	50.5	63.2	16.9	36.8
After 72 hr	58.4	23.7	41.6	74.6	15.8	25.4
After	69.6	22.8	30.4	84.3	14.4	15.7

96 hr						
After 120 hr	**78.8**	**22.1**	**21.2**	**89.1**	**13.3**	**10.9**
After 144 hr	**89.2**	**21.4**	**10.8**	**92.6**	**12.1**	**7.4**
After 168 hr	**94.3**	**19.3**	**5.7**	**96.1**	**11.2**	**3.9**

After incubation, the presence of turbidity and gas constitutes a positive presumptive test for coliforms. The absence of turbidity and gas requires a second incubation for 24 ± 2 hours at 35 ± 0.5 ^{o}C. Failure to produce turbidity and gas (i.e. shades of yellow color) within 48 hours ± 3 hours indicates fecal coliforms are not present. Combination number of positive tubes of the highest dilution and the next two higher dilutions are used to determine the MPN index/100 ml value from a table. This index value is used to compute the MPN /g dry solid according to the following equation **(USEPA, 1999; USEPA, 2005)**:

MPN/g solid = (10×MPN index/100 ml)/(largest volume×% dry solid) ------- (c)

Figure (2): Fecal Coliform Inoculated Test Tubes.

The results of fecal coliform densities with time for mixes proportion which satisfy the required pH are presented in table (11).

Table (11): Fecal Coliform Densities of Treated Thickened and Dewatered Sludge.

Time intervals	ecal Coliform Density (MPN/G Solid) Of Thickened Sludge Treated With 20 % CKD	Fecal Coliform Density (MPN/G Solid) Of Dewatered Sludge Treated With 30 % CKD
After 4 hrs	1.20×10^{7}	2.40×10^{6}
After 12 hrs	6.22×10^{5}	4.0×10^{5}
After 24 hrs	3.16×10^{4}	1.11×10^{4}
After 72 hrs	1.76×10^{3}	1.47×10^{3}
After 120 hrs	1.01×10^{3}	8.5×10^{2}
After 168 hrs	4.1×10^{2}	2.2×10^{2}

4- Results and Discussion

4.1- This work was conducted to examine the stabilization potential of sewage sludge. Sludge stabilization was performed using CKD as alkaline agent which is an inorganic waste material resulting from the cement industry. The results obtained from this study were analyzed in accordance with the requirements of part 503 of the 40 CFR regulation of the U.S. EPA. The part 503 rule defines two types of biosolids (sludge) with respect to pathogen reduction: Class A, where, the density of fecal coliform in the sewage sludge should be less than 1000 most probable number (MPN) per gram of total solids and class B, where the density of fecal coliform in the sewage sludge should be less than 2 million (MPN) per gram of total solids. Both classes are safe, but additional requirements are necessary with class B materials **(USEPA, 2000)**.

4.2- The pH of the sludge/alkaline materials mixture must be above 12 for 2 hours and subsequently maintained above 11.5 for 22 hours to meet pathogen and vector attraction reduction requirements by alkaline addition. The importance of measuring the pH during alkaline stabilization is based on the relationship of this parameter to pathogen destruction (**USEPA, 1999)**.

4.3- The pH levels of six mixes, of each sludge, have treated with different ratio addition of CKD were monitored at 2, 12, 24, 72, 120 and 168 hours. At 2 hours, the mixes containing thickened sludge with a minimum of 15 % CKD and mixes containing dewatered sludge with a minimum of 25 % CKD attained an initial pH of ≥ 12. At 24 hours, the mixes containing thickened sludge with a minimum of 20 % CKD and mixes containing dewatered sludge with a minimum of 30 % CKD were able to maintain required pH values of ≥ 11.5.

4.4- As shown in figure (3), rapid increases in pH values for both thickened sludge treated with 20 % CKD and dewatered sludge treated with 30 % CKD were occurred during short period of time at the beginning of sludge treatment due to the alkaline CKD addition. The pH of the treated sludge must be maintained at the required level for an adequate time, as mentioned above, to destroy pathogens. The chemical added must provide enough residual alkalinity to maintain a high pH until the product used or disposed of because high pH prevents growth or reactivation of odor-producing and pathogenic organisms. Drop in pH, referred to as pH decay, occurs due to water filtration (leach out) which is the washing out the mixture's residual alkalinity through perforated plate of cylinders' bottom of drying apparatus at drying stage, allowing the pH to drops to 11.5 then gradually decrease to about 11.

4.5- Treating sewage sludge by the addition of sufficient quantity of CKD to raise the pH level to achieve reduction in pathogen resulted in an increase in solid content of the sludge. It was necessary to dry the stabilized sludge to moisture content preferably less than 10 % to prevent pathogen re-growth in conjunction with alkaline environment **(WEF, 2006)**. Drying method used in this study consisted of applying air to the resulting mixture. A constructed lab apparatus, as shown previously in figure (1), was designed to this purpose. Where, after conveying sludge mixtures to the cylinders of apparatus, the bottom perforated plate permit sludge dewatering to an intermediate solid level as a cake material. Then, the air which was supplied for 6-8 hours per day was vented through the mixtures of treated sludge to accelerate drying and contribute to the oxidation of volatile solids.

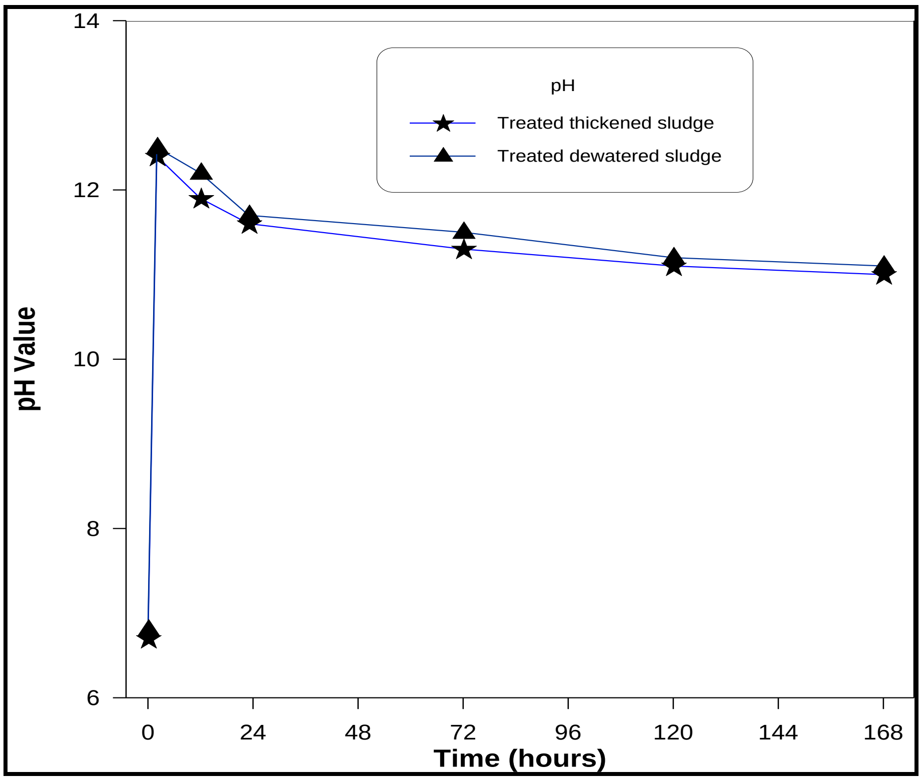

Figure (3): Ph Versus Time for Thickened Sludge Treated With 20% CKD And Dewatered Sludge Treated With 30% CKD.

4.6- Vectors which include flies, mosquitoes, rodents, and birds, can transmit pathogens to humans physically or through playing a specific role in the life cycle of a specific pathogen. Reducing the attractiveness of processed solids to vectors reduces the potential for transmitting diseases. Sewage sludge is considered to have undergone adequate vector attraction reduction if sufficient alkali is added to raise the pH level to at least 12 and maintain it for two hours or maintain a pH of at least 11 for 22 hours **(USEPA, 1999)**.

Thickened sludge treated with 20 % CKD and dewatered sludge treated with 30 % CKD as shown in table (10) could met the vector attraction requirements with regard to pH level.

Reduction of vector attraction is achieved if the mass of volatile solids in the treated sludge is reduced by at least 38 % **(USEPA, 1999)**. Volatile solids content of sludge is an indication of sludge stability; hence, reduction of volatile solids is used for assessing the effectiveness of a process in stabilizing sludge. Figure (5) shows the change in volatile solid content as percent to the total solid with time for thickened sludge and dewatered sludge treated with 20% and 30% CKD respectively. As shown the rapid decrease in volatile solids percent is due to the CKD addition which is an inorganic solid material. Then, a slow decay in volatile solids percent is observed as a result of oxidation of organic matter by vent air used for sludge drying.

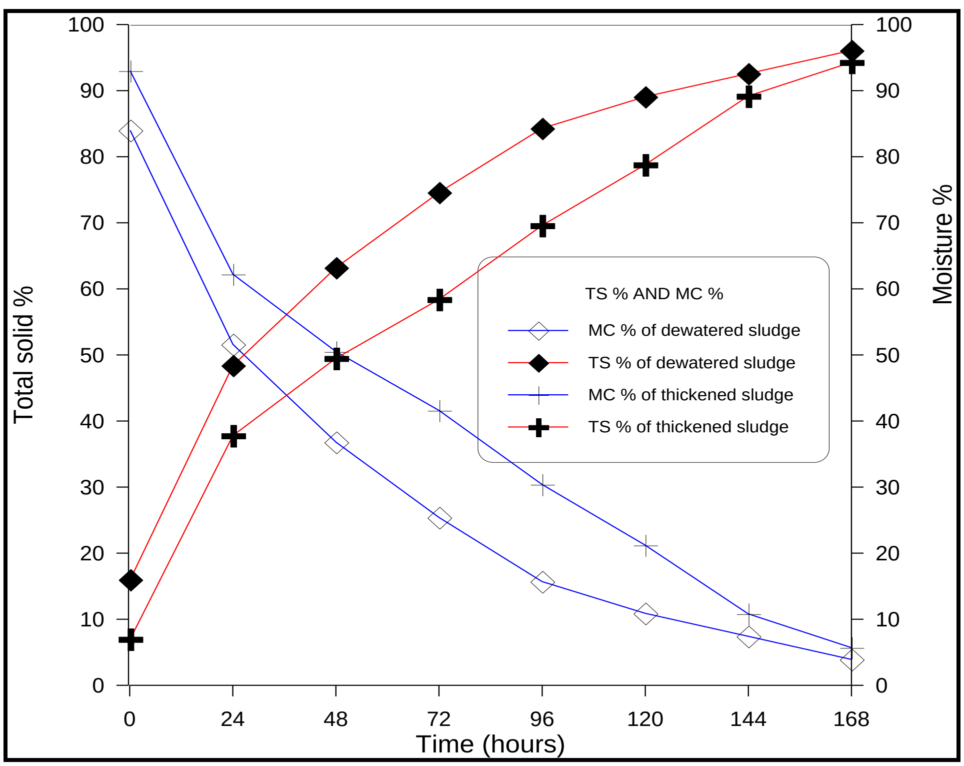

Figure (4) Total Solid Percent and Moisture Content Variation with Time

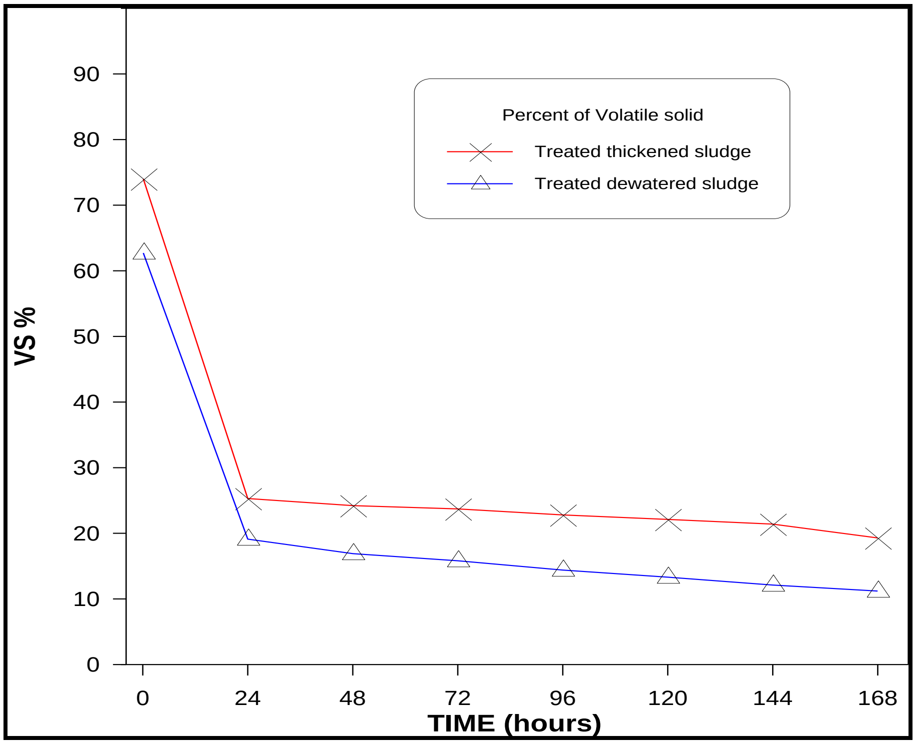

Figure (5): Variation Trend of Volatile Solid Percent versus Time.

4.7- Alkaline amendments using CKD instead of lime have been applied as a dry dust in sufficient quantities to raise the pH level and decrease the moisture content of the sludge to a low level which impedes microbial growth. The EPA part 503 regulations require that fecal coliform density may not exceed 1000 MPN/g of solids if the sludge is to partially qualify as class A sludge, or less than 2×10^{6} MPN /g of solids if the sludge is to qualify as class B sludge. These standard limits were compared with the experimental results to determine the CKD dose (addition) needed to meet these criteria.

Fecal coliforms are a group of bacteria that are defined by their ability to use lactose for growth when incubated at elevated temperatures. With respect to biosolids, fecal coliforms are also used as indicators or measure of process effectiveness in reducing microbial densities **(WEF, 2006)**.

Before CKD addition, the fecal coliform densities as illustrated in table (3.10) were 2.43×10^{8} MPN/g of solids for thickened sludge and 8.75×10^{7} MPN/g of solids for dewatered sludge. After CKD addition, the mixes proportion which satisfy the required pH were further monitored for fecal coliform densities with time and the results are presented in table (3.14). MPN of fecal coliform per gram of solid have been calculated by the combination of positive tubes for a series of dilutions. About 99 % decrease in fecal coliform count was observed as shown in figure (4.10) after 12 hours upon mixing the samples of sludge with CKD.

Thickened and dewatered sludge treated with 20 % and 30 % CKD, respectively met the requirements for class B after 12 hours. Where, the MPN of fecal coliform was 6.22×10^5 and 4.0×10^5 per gram of solid for thickened sludge treated with 20 % CKD and dewatered sludge treated with 30 % CKD, respectively. At 120 hours, thickened and dewatered sludge amended with 20 % and 30 % CKD, respectively, met class A requirements with fecal coliform densities about 1000 MPN/g of solid and 850 MPN /g of solid for thickened and dewatered sludge, respectively.

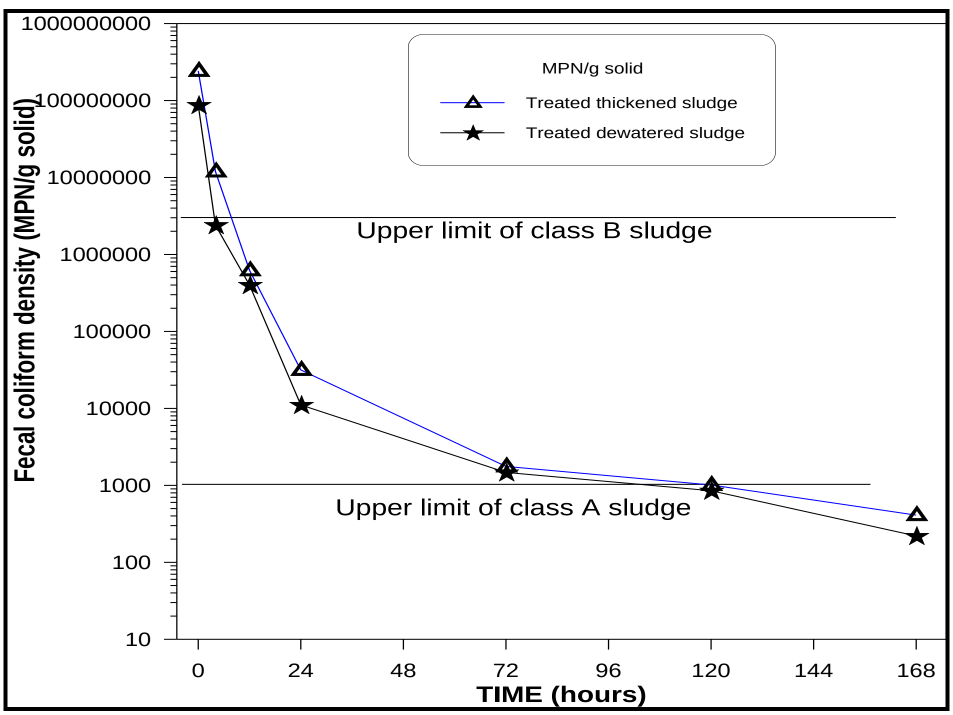

Figure (6): Variation of Fecal Coliform Densities of Treated Sludge with Time.

Examination of thickened sludge treated with 15 % CKD and dewatered sludge treated with 25 % CKD after 24 hours of treatment showed that the fecal coliform densities of treated sludge achieve class B requirements. Where the fecal coliform density was 5.4×10^5 MPN/g solid for thickened sludge and 3.72×10^5 MPN/g solid for dewatered sludge, the dose needed to meet the pH criteria is higher than the dose needed to reduce the density of fecal coliform, which guarantees that the pH-time criteria set by the US EPA are adequate to meet the fecal coliforms requirement.

Examination of final sludge produced at Al-Rustamiyah treatment plant as illustrated in table (12) which was treated by sun on drying bed shows that the average value of fecal coliform density is 1.49×10^6 MPN per gram of solid which met the class B sludge according to the US EPA requirements.

Table (12) Characteristics Of Final Sludge Produced At Al-Rustamiyah Plant.

pH	% TS	% VS	FC (MPN/g solid)
6.8	94	21	1.49×10^6

Comparison between fecal coliform densities in treated sludge with CKD and sludge produced at Al-Rustamiyah plant with pathogen reduction requirement of class A and B is shown in figure (7). This figure indicates that treating sludge with CKD could achieve class A requirements while sludge produced at Al-Rustamiyah plant achieve class B requirements.

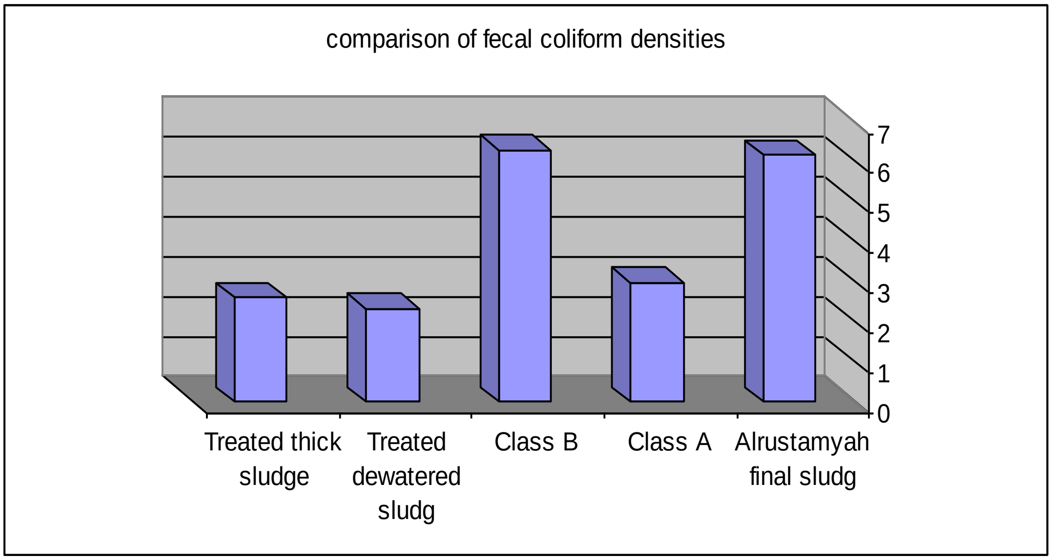

Figure (7) Comparison of Log Values of Fecal Coliform Densities

REFERENCES:

1- Al-Najjar, Abdulfattah Ahmed Ameen, (2001), " Evaluation of Sludge Treatment in Al-Rustamiyah Sewage Treatment Plant-3rd Extension", MSc. Thesis, University of Technology.

2- APHA, (1995), Standard Methods for the Examination of Water and Wastewater 18th edition, American Public health Association.

3- APHA, (1995), Standard Methods for the Examination of Water and Wastewater 18th edition, American Public health Association.

4- Burnham, C. Jeffry, Hatfield, Nancy, Bennett, F. Gary and Logan, J. Terry, 2000, " Use of Kiln Dust With Quicklime for Effective Municipal Sludge Pasterization and Stabilization With the N-Viro Soil Process ", www.patentstorm.us/patents/5997599.

5- Christine, L. Bean; Jacqueline, J. Hansen; Aarone, B. Margoline and Giovanni Widmer, (2007), " Class B Alkaline Stabilization to Achieve Pathogen Inactivation", Int. J. Environ. Res. Public Health, Vol. 4, No. 1, www.mdpi.org/ijerph/papers/ijerph2007010009.pdf.

6- European Commission, 2001, " Reference Document on Best Available Techniques in the Cement and Lime Manufacturing Industries ", IPPC Document, www.jrc.es/pub/english.cgi/d733211/03.

7- Investment Department, 2007, " Investment Opportunities to Implement New Cement Plants in Iraq", Ministry of Industry and Minerals, Republic of Iraq.

8- Naik, R. Tarun, Canpolat, F. and Chun, Y., 2003, "Uses of CKD other than for flue gas desulfurization", http://www.uwm.edu/dept/CBU/abstracts/03-529.pdf.

9- Paulauskas, Valdas; Sabiene, Nomeda and Zaleckas, Ernestas, 2006, "Wastewater Sewage Sludge Leaching and Alkaline Stabilization", EKOLOGIJA, No. 4, Lithuania University of Agriculture.

10- Tchobanoglous, George and Schroeder, Edward D., 1985, " Water Quality-Characteristics, Modeling and Modification", Addison-Wesley Publishing Company, Inc.

11- UKEA, 2001, "Guidance for the Cement and Lime Sector", IPPC, Version 1, www.sepa.org.uk/pdf/ppc/uktech/ippc_s3_01.pdf.

12- UNEP, 1997, "Global Environment Outlook-1: Global State of the Environment- Chapter 3: Policy Responses and Directions", http://www.grida.no/geo1/ch/ch3_28.

13- UNEP, 2006, "Iraq Institutional Capacity Assessment Report", http://postconflict.unep.ch/publications/ICA_iraq.pdf.

14- UNEP, UNEP in Iraq, 2007, " Post-Conflict Assessment, Clean-up and Reconstruction", http://postconflict.unep.ch/publications/Iraq.pdf.

15- USEPA, 1999, " Environmental regulations and technology: Control of pathogens and Vector attraction in sewage sludge; EPA/625/R- 92/013, Office of Research and Development, http://www.epa.gov/ORD/NRMRL.

16- USEPA, 2000, " Biosolids Technology Fact Sheet – Alkaline Stabilization of Biosolids", www.epa.gov/region8/biosolids/biosolidsdown/BiosolidsTechSheetAlk.pdf.

17- USEPA, 2005, " Method 1680: Fecal Coliforms in Sewage Sludge by Multiple Tube Fermentation Using Lauryl Typtose Broth (LTB) and EC Medium", EPA-821/R-04-026, Office of Water, USEPA.

18- USEPA, 2006, " Mineral Products Industry-Portland Cement Manufacturing", http://www.epa.gov/ttn/chief/ap42/ch11/final/c11s06.pdf.

19- Vesilind, P. Aarne, 1979, " Treatment and Disposal of Wastewater Sludge ", ANN ARBOR SCIENCE Publishers INC.

20- WEF, 2006, " Reactivation and Regrowth of Fecal Coliform in Anaerobically Digested Biosolids", Water Environment Federation, http://www.wef.org/science technology resources/biosolids/reactivationFecalColiform.htm.